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APPLICATION

BORIS: a free, versatile open-source event-logging software for video/audio coding and live observations

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Summary

1. Quantitative aspects of the study of animal and human behaviour are increasingly relevant to test hypotheses and find empirical support for them. At the same time, photo and video cameras can store a large number of video recordings and are often used to monitor the subjects remotely. Researchers frequently face the need to code considerable quantities of video recordings with relatively flexible software, often constrained by species-specific options or exact settings.

2. BORIS is a free, open-source and multiplatform standalone program that allows a user-specific coding environment to be set for a computer-based review of previously recorded videos or live observations. Being open to user-specific settings, the program allows a project-based ethogram to be defined that can then be shared with collaborators, or can be imported or modified.

3. Projects created in BORIS can include a list of observations, and each observation may include one or two videos (e.g. simultaneous screening of visual stimuli and the subject being tested; recordings from different sides of an aquarium). Once the user has set an ethogram, including state or point events or both, coding can be performed using previously assigned keys on the computer keyboard. BORIS allows definition of an unlimited number of events (states/point events) and subjects.

4. Once the coding process is completed, the program can extract a time-budget or single or grouped observations automatically and present an at-a-glance summary of the main behavioural features. The observation data and time-budget analysis can be exported in many common formats (TSV, CSV, ODF, XLS, SQL and JSON). The observed events can be plotted and exported in various graphic formats (SVG, PNG, JPG, TIFF, EPS and PDF).

Key-words: behavioural analysis, behaviour coding, coding scheme, ethology, observational data, time-budget

Introduction

The methods used in behavioural sciences have changed dramatically in recent years due to the increasing availability of quantitative data. Researchers interested in collecting behavioural data to investigate the decision processes and communication strategies in humans and animals have taken advantage of new tools and approaches (e.g. Knopien, van der Pers & van Delden 2000; Baker 2011; Shteynberg *et al.* 2014). The use of photo and video cameras and audio recorders that can store a large amount of data is now widespread in fields like psychology, primatology, entomology, anthropology, ornithology, medicine, neuroscience and cognitive science (e.g. Leong *et al.* 2003; Cristani *et al.* 2013). There is also an increasing use of remote monitoring where researchers collect an impressive amount of data, which they have then to review to extract the target events (van Dam *et al.* 2013; Li *et al.* 2015). Computer-aided programs are thus instrumental in

ensuring a manageable process that can lead to results (Visser 1993; Noldus *et al.* 2000).

Observational approaches to studying human and animal behaviour lead to the commercial availability of various softwares that gradually developed into massively complicated applications, applicable to a multitude of particular systems and solutions (Spink *et al.* 2001; van Dam *et al.* 2013). The increasing complexity of these programs led to their development into relatively expensive suites of software. They satisfy the requirement of very specific research but may be inaccessible to other researchers, in particular to those working in institutions with an interest in behaviour or those that are not affiliated with universities. Traditionally, commercial software also had limitations regarding the computers suitable to run the programs and were useable on a limited number of operating systems (e.g.; Observer XT, Noldus 2015; INTERACT, Mangold 2015), while usually offering a powerful set of analytical features (Adamson *et al.* 2013; Spitzen *et al.* 2013).

The answer to the increasing difficulty in accessing commercial software for observational research leads to the rise of free

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tools for the quantitative analysis of behaviour (e.g.; JWatcher, Blumstein & Daniel 2007). They were usually simpler in terms of functions available and analysis routines. Most importantly, they lost the feature of a time-constrained integration between video playing and user coding (Blumstein & Daniel 2007).

BORIS integrates a highly customizable and flexible interface with time-constrained event logging that can be managed by pressing the keys on the keyboard. It can be used for various types of sampling (e.g. focal and scan sampling, Altmann 1974), and several subjects can be observed within the same project. The program allows the calculation of time-budgets and provides statistics for the duration, occurrence and intervals of the events.

BORIS (Behavioural Observation Research Interactive Software)

BORIS is available for Microsoft Windows, Mac OS X and GNU/Linux platforms at <http://www.boris.unito.it>. The Python3 source code is released under the GNU General Public License at <https://github.com/olivierfriard/BORIS>.

Reviewing and coding visual and audio information in BORIS is easy and intuitive because of the integrated playback in which the time offsets of media files are recorded. Playing a variety of audio and video formats is a critical issue in any media-based program. BORIS is based on the popular VLC multimedia player libraries, which is a free and open-source cross-platform framework.

A BORIS project file is a container for all information related to a set of observations, such as the ethogram, the independent variables and the subjects. BORIS allows an unlimited number of projects, but only one project can be opened at a time. The time format can be set to either seconds or hours.

Defining the ethogram is the first essential step before starting logging behavioural events. This process is completely customizable and is when events are associated with keys. Alternatively, the user can set the ethogram from scratch, import an existing ethogram from another BORIS project, or import an ethogram from a JWatcher project (Blumstein & Daniel 2007). The behaviour type can be defined as a 'point event' or 'state event'. To enable more complex coding (e.g. facial expression coding; spatial position in a grid), the user can also add a 'coding map' to either a state or a point event. Each behaviour can be associated with a keyboard key that will then be used to log the behavioural events. The same key can be associated with more behaviours. In this latter case, BORIS will pause and ask which of the behaviours associated with that key the user wants to record. The keys are case insensitive. A description of each behaviour can be added and can be useful to standardize observations between different users. For each behaviour, a series of modifiers can be added.

The modifiers can be used to add attributes to behaviours. A single behaviour can have two or more modifiers attached (e.g. 'play' may have 'solitary' or 'social' as modifiers). The use of modifiers can be convenient to significantly reduce the number of keys and simplify the behavioural coding. In BORIS, modifiers can also be added in different sets [e.g. 'play, social' may have a modifier set (#1) for 'brothers' and another (#2) for 'sisters']. Mutually exclusive states can be set in an exclusion matrix so that the beginning of an event will correspond with the end of another. We worked to ensure that users can freely organize the behavioural codes and decide whether they want to use modifiers or assign more codes to the same key.

The user interface has a toolbar, which, along with the other modules, can be undocked. It features popular video controls

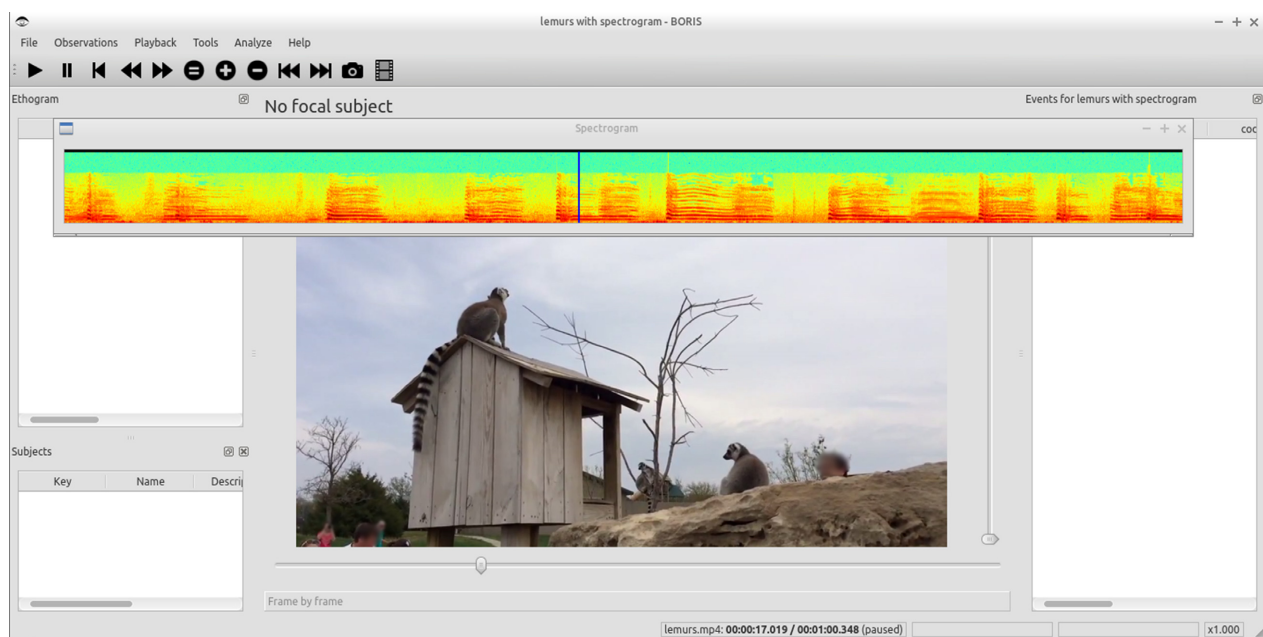


Fig. 1. Sound spectrogram in BORIS. While screening a media (audio or video), a synchronized spectrogram can be produced by a native function.

for play, pause, stop and fast forward/backward. BORIS can be switched on and off to a frame-by-frame mode during observations and slowed down to a desired percentage of the original tempo. This feature makes it possible to analyse each step in the video easily, with more detail and focus on a particular display (e.g. muscle contractions, subtle gestures). With a click, the user can capture still frames.

The accuracy of the video coding can be improved by repeated views of a media if needed. Once moving across the

media, each key pressed results in the insertion of a behavioural display at the time in which it occurs in the video. The occurrence of a behaviour in an individual can be reviewed using a graphical representation or by generating a time-budget analysis. Collected data can be exported in many formats (e.g. TSV, CSV, ODF, XLS, SQL and JSON) to allow further analysis.

In recent years, remote video camera traps have been used for population assessment and for capturing behavioural traits of elusive species (Tan, Yang & Niu 2013). They are a valuable

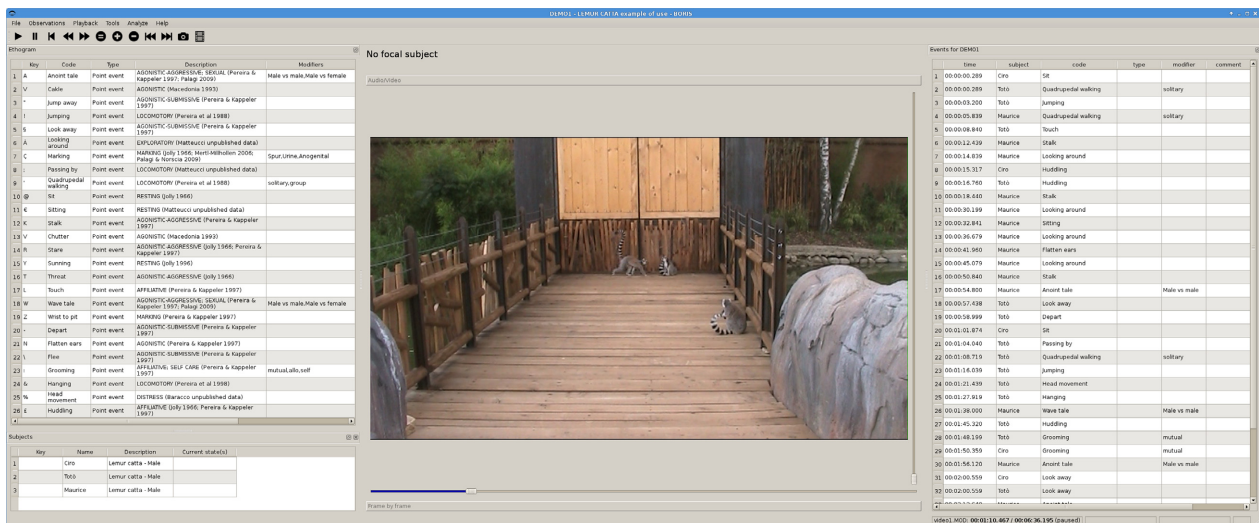


Fig. 2. The main window during an observation. The modules Ethogram, Subjects, Video and Events are visible. Each module can be undocked to better fit your monitor(s).

Time budget										
Selected observations										
DEMO1										
Total media length: 00:02:32.240										
	Subject	Behavior	Modifiers	Total number	Total duration (s)	Duration mean (s)	Duration std dev	Inter-event intervals mean (s)	Inter-event intervals std dev	% of total media length
1	Ciro	Huddling	NA	2	77.041	38.521	8.657	45.841	NA	50.6
2	Ciro	Look away	NA	1	-	-	-	NA	NA	-
3	Maurice	Anoint tale	NA	3	-	-	-	39.42	30.971	-
4	Maurice	Flatten ears	NA	1	-	-	-	NA	NA	-
5	Maurice	Flee	NA	1	-	-	-	NA	NA	-
6	Maurice	Looking around	NA	2	7.321	3.661	1.445	29.4	NA	4.8
7	Maurice	Quadrupedal walking	NA	1	5.88	5.88	NA	NA	NA	3.9
8	Maurice	Sitting	NA	1	-	-	-	NA	NA	-
9	Maurice	Stalk	NA	2	-	-	-	32.4	NA	-
10	Maurice	Wave tale	NA	2	-	-	-	35.64	NA	-
11	Totò	Depart	NA	1	-	-	-	NA	NA	-
12	Totò	Hanging	NA	1	27.234	27.234	NA	NA	NA	17.9
13	Totò	Head movement	NA	2	-	-	-	6.96	NA	-
14	Totò	Huddling	NA	2	74.878	37.439	6.449	46.561	NA	49.2
15	Totò	Jumping	NA	2	-	-	-	72.839	NA	-
16	Totò	Look away	NA	2	-	-	-	63.121	NA	-
17	Totò	Passing by	NA	3	-	-	-	44.1	52.524	-
18	Totò	Quadrupedal walking	NA	UNPAIRED	UNPAIRED	UNPAIRED	UNPAIRED	UNPAIRED	UNPAIRED	-

Fig. 3. The time-budget analysis for the observation DEMO1. Total number, total duration, duration mean, duration standard deviation, inter-event intervals duration mean, inter-event intervals standard deviation and percent of the total time for each subject and each behavior are shown.

monitoring tool and enable long-term spatiotemporal monitoring, which usually results in a series of short videos of fixed duration (from the triggering of motion detectors to a programmed delay time). Once the video footage is downloaded from the camera traps onto a computer, the behavioural biologist faces the challenge of coding this long series of very short videos. Within a single observation, BORIS has a particular function for this task, which allows the automatic loading of all videos from a selected directory and the interrupting all the current states when passing from one video footage to another. This feature enables a more convenient identification of the actual observation time of the target individuals and an easier switching between individuals that may occur in one video but not in the following one.

While screening the video, the program also allows the visualization of a sound spectrogram of the associated audio information. A spectrogram (or sonogram) is the visual representation of a sound that shows frequencies (on the vertical axis) with variation in time (on the horizontal axis, Fig. 1). The degrees of amplitude are represented as colour gradients. A spectrogram facilitates the recognition of common acoustic structures and can be crucial in associating a particular behaviour with concurring vocalizations. The program also features an analytical measurement tool that allows measuring angles, distances and areas from the video (Fig. S7).

Example of use

To showcase the main functions of BORIS, we present behavioural coding performed by Dr. Valentina Matteucci on the video recordings of a captive colony of ring-tailed lemurs (*Lemur catta*) at the ZOOM Torino zoological park (www.zoomtorino.it), Cumiana, Italy. Recordings were made with a commercial camcorder Panasonic HC-V720. Dr. Matteucci, in collaboration with OF and MG, compiled the complete ethogram of the ring-tailed lemur from previous research (Jolly 1966; Evans & Goy 1968; Pereira, Seeligson & Macedonia 1988; Macedonia 1993; Oda 1996; Pereira & Kappeler 1997; Wilson 2002; Mertl-Millhollen 2006; Palagi 2009; Palagi & Norscia 2009; Sclafani *et al.* 2012). Additional behaviours were added after observations by Matteucci and Baracco (unpublished data). The resulting BORIS file containing the full behavioural repertoire of the ring-tailed lemur is available at <http://www.boris.unito.it/files>. It comprises 104 behaviours (Appendix S4).

As an example of use, we selected six subjects for the observations using their in-house names (Ciro, Totò, Maurice, Fossar, Giulian, Seven). Dr. Matteucci coded three videos in BORIS at half speed and scored the results indicating the occurring behaviours and subjects (Appendix S5). To simplify the visualization of the analyses we show here, the behavioural

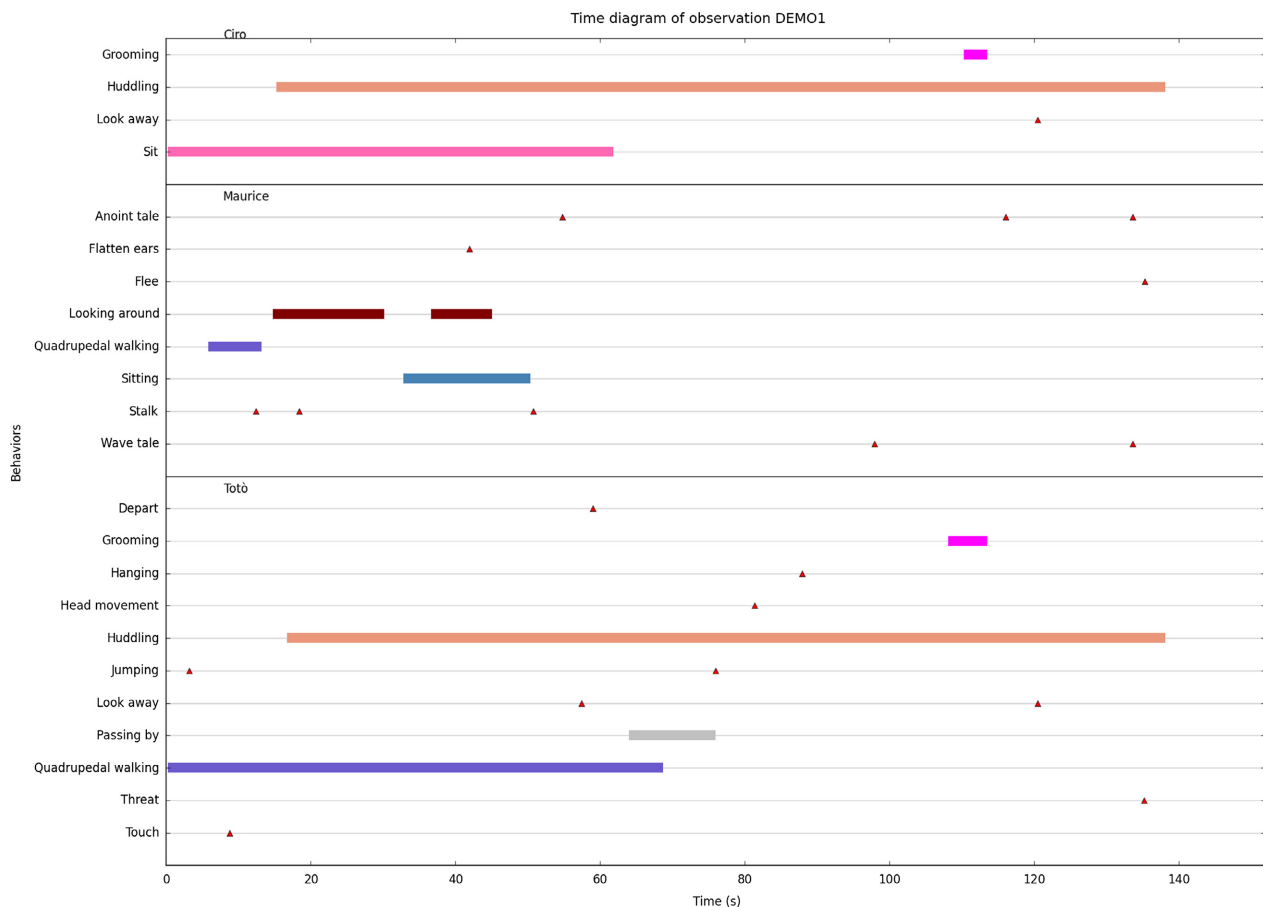


Fig. 4. Time diagram of the recorded events for the observation DEMO1. The events for each subject and for each behavior are plotted against time.

repertoire in these videos has been reduced considerably, from 104 to 26 behaviours. In Fig. 2, we show the composite view of the ethogram, subjects, video and events tabs for the observation DEMO1. To visualize the occurrence of each behaviour and the individual time-budget, we used the time-budget function in BORIS ('Analyze' > 'time budget'; Fig. 3). The time budget can be calculated from several observations by selecting them from the observation list (e.g. recordings on the same day). In this example, we analysed three different observations together (observations DEMO1, DEMO2 and DEMO3 corresponding to videos in Videos S1, S2 and S3, respectively). For each subject, we visualized the occurrence of behaviours and the duration of each state ('Analyze' > 'plot events'; Fig. 4).

Conclusion and future directions

BORIS offers a customizable and intuitive interface for behavioural observations, implementing novel ideas and widely used functionalities (Table S6). The user fully controls the lists of behaviours and subjects. These lists can be exchanged between projects, modified and shared with colleagues. Coding of the audio and video files can be performed at various speeds, but also switched to a 'frame-by-frame' video analysis. Event recordings are activated by pressing a key when the corresponding behaviour occurs.

We have made improvements on earlier versions to make it easier for users to code multiple video files within the same project. The result is better management of the 'observation list' with regard to both setting the project and in the calculation of the time budget and the data visualization.

We are currently working on the integration of Web services (e.g. sequential analysis), which will be able to receive information from a BORIS project.

The features of this program fit well with the current academic and institutional scenario, where a profound scientific understanding of data must be achieved with flexible and affordable tools.

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Data accessibility

Videos and BORIS project files used for testing are available in the supplemental documents. A features comparison table against popular observational data software is available as supporting information.

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Supporting Information

Additional Supporting Information may be found online in the supporting information tab for this article:

Video S1. Video recording of a captive colony of ring-tailed lemurs (*Lemur catta*) at ZOOM Torino.

Video S2. Video recording of a captive colony of ring-tailed lemurs (*Lemur catta*) at ZOOM Torino.

Video S3. Video recording of a captive colony of ring-tailed lemurs (*Lemur catta*) at ZOOM Torino.

Appendix S4. *Lemur catta* ethogram. BORIS project files containing an ethogram with 104 codified behaviors.

Appendix S5. Example of use. BORIS project files containing three observations, of Videos S1, S2, and S3, respectively.

Table S6. Features comparison table across popular observational data software.

Figure S7. Example of use. Distance measurement.